

Revisiting The Hearing Screening Protocol: Should 6000Hz be Included?

CAPSTONE PROJECT

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of

Audiology in the Graduate School of The Ohio State University

By

Laura E. Feeney, B.A.

The Ohio State University

Capstone Committee:

Wayne King, Advisor
Gail M. Whitelaw
Christy Goodman
Stephanie Davidson

Approved by

Advisor,
Department of Speech and
Hearing Sciences

ABSTRACT

School hearing screenings are performed to identify children at risk for hearing loss. Current protocols in the state of Ohio include pure tone screening at 1000, 2000, and 4000Hz with tympanometry being an optional screening test. Although this screening does identify children at risk for hearing loss, there is a possibility that children with high frequency hearing loss may not be identified. In this study, 400 students in fifth and ninth grades were screened using pure tone audiometry at 1000, 2000, 4000, 6000Hz, and tympanometry. Without knowing whether or not the students who referred on the initial screening in fact had hearing loss, it cannot be concluded whether or not 6000Hz should be included in the screening protocol. However, preliminary data was collected from this screening, which revealed that there was no significant difference between gender or grade level in the screening. The initial data confirms an increased number of students who do not pass the experimental screening protocol including 6000Hz than the standard protocol. This is an extremely high referral rate, and would presumably include many false positives, higher than the referral rate expected from a screening with the established prevalence of known hearing loss.

ACKNOWLEDGMENTS

I wish to thank Dr. Gail Whitelaw for her support and guidance to make this Capstone possible. I am grateful to all graduate students and coworkers who took the time to help screen children for this project. I wish to thank the Columbus Catholic Diocese schools that allowed their children to participate in the screenings. Thank you for allowing the time for your children to be part of this research study.

Thank you to my family for supporting me throughout the process of this paper and the last four years of Graduate School.

TABLE OF CONTENTS

Abstract.....	ii
Acknowledgements.....	iii
Index of Figures.....	v
Introduction.....	1
1.1 Early Identification of Hearing Loss.....	2
1.2 Hearing Screening in School.....	3
1.2.1 Ohio Department of Health Screening Guidelines....	6
1.2.2 The Need for Changes to the Screening Protocol....	8
Methods and Results.....	12
2.1.1 Participants.....	12
2.1.2 Procedures.....	12
2.1.2.1 Data Collection.....	13
2.1.2.2 Data Analysis.....	14
2.2 Results.....	15
2.3 Discussion.....	22
References.....	24
Appendix A.....	27
Appendix B.....	29

Index of Figures

Figure 2.1: Failures by frequency for the entire sample of N=400 subjects.....	15
Figure 2.2: Unilateral and bilateral failures by frequency.....	17
Figure 2.3: Cumulative failures by frequency for the entire sample (N=400).....	18
Figure 2.4: Cumulative failures by frequency and gender.....	19
Figure 2.5: Percentages of failures by grade and gender.....	20

Introduction

Congenital hearing loss is one of the most common birth defects affecting approximately 3 infants per 1000 (Cunningham & Cox, 2003; Kemper & Downs, 2000). Congenital hearing loss is three times more common than Down's syndrome, six times more common than spina bifida and fifty times more common than phenylketonuria (Smith et al, 2005). In spite of these statistics, it is certain that the incidence of permanent sensorineural hearing loss in the pediatric population is underestimated because only cases of hearing loss identifiable by newborn infant screening are included. The point prevalence of hearing loss in the pediatric population is difficult to assess because that figure includes individuals with acquired permanent hearing loss, delayed onset congenital hearing loss, and children with temporary hearing impairment (e.g. otitis media). The Centers for Disease Control and Prevention (2006) report that 1.2% (70,767) of the children served under the Individuals with Disabilities in Education Act (IDEA) in the 2000-2001 school year received services for hearing. Of the 738,000 individuals in the United States with severe to profound hearing impairment, Blanchfield et al (2001) report that 8% are under eighteen years old.

Hearing loss in children can result from a number of congenital and acquired conditions. About 70% to 80% of congenital hearing loss is estimated to be nonsyndromic, while the remaining cases are caused by specific genetic syndromes (Milunsky et al., 2000). Mutations of the GJB2 gene are thought to account for roughly half of hereditary sensorineural hearing loss (Smith et al., 2005). Infectious diseases such as meningitis, trauma, ototoxic pharmacologic agents, and noise exposure are frequently cited as causes of acquired hearing loss (Cunningham & Cox, 2003). Meningitis is the most common cause of acquired sensorineural hearing loss in children, accounting for about 6% of all cases (Smith et al., 2005).

Regardless of etiology, early identification of these children is critical due to the deleterious consequences of unremediated hearing loss on the child's cognitive and psychosocial development. Successful learning and socialization crucially depend on the child's ability to acquire the requisite receptive and expressive language skills. Both of these abilities are demonstrably compromised by even mild degrees of hearing loss. A large body of research has demonstrated that children with hearing loss are at a significant disadvantage to their normal-hearing peers (Yoshinaga-Itano et al., 1995). Twenty three to twenty five percent of children with a unilateral or bilateral hearing loss will repeat a grade in school and children with even minimal hearing loss have demonstrated difficulty listening in the classroom (Johnson et al., 1997; Logemann and Baum, 1998).

1.1 Early Identification of Hearing Loss

Fortunately, the aforementioned negative consequences of hearing loss in the pediatric population are not inevitable. Research has demonstrated that the achievement gap between children with and without hearing impairment can be substantially reduced by early and effective remediation. Yoshinaga-Itano and colleagues (1995) found that children have significantly better language outcomes if hearing loss is diagnosed and early intervention is in place by 6 months. This study and similar research provided the impetus for the Joint Committee on Infant Hearing's "Year 2000 Position Statement: Principles and Guidelines for Early Hearing Detection" (JCIH, 2000). An earlier version of the JCIH position statement was largely endorsed and reiterated in the American Academy of Pediatrics statement: "Newborn and Infant Hearing Loss: Detection and Intervention" (AAP, 1999). The JCIH position statement suggests a 1-3-6 model to identification and early intervention. They suggest that screening should be completed

by one month of age, diagnosis should be completed by three months, and intervention should ideally occur before six months of age.

The Joint Committee on Infant Hearing (JCIH) recommends specific guidelines for states to follow when mandating newborn hearing screenings. Ohio, and thirty-six other states have heavily relied on the JCIH recommendations in implementing universal newborn infant screening programs. The JCIH recommends that automated “objective” nonbehavioral measures are used in the screening process. Specific recommendations are made for the use of otoacoustic emissions (OAEs) and automated auditory brainstem testing (AABR). Click AABR and OAEs are limited in their ability to identify congenital hearing loss. Both are constrained to a frequency range of approximately 1000-4000Hz in typical screening protocols (Gorga et al, 2000; Sininger et al, 2000). Further, neither is sensitive to mild forms of hearing impairment. Finally, just as with any diagnostic measure, a certain proportion of children with hearing impairment will yield false “pass” results. A recent study estimated that OAEs and AABR identify 78% of congenital hearing loss (Kemper & Downs, 2000)

1.2 Hearing Screenings in the School

While OAEs and AABR are invaluable tools in newborn infant screening, there is a recognized need in the pediatric audiologic community for follow up screening (Cunningham & Cox, 2003). In addition to the children not correctly identified by infant screening procedures, the number of children with later developing congenital hearing impairment and acquired hearing loss is sufficient to warrant additional universal screening. Another reason for repeated screenings as the child matures is the reliability of nonbehavioral audiologic test results. Behavioral audiometry is the standard in the assessment of auditory sensitivity. OAEs and ABR are only screening tests and hearing cannot be definitively considered normal until reliable

behavioral results are obtainable. In a typically developing child, reliable ear-specific behavioral thresholds typically cannot be acquired until that child reaches about 4 years of age.

With the acknowledged necessity of universal hearing testing subsequent to newborn infant screening, the question becomes how the program should be implemented. The schools are an ideal environment to perform these screenings because school attendance is mandated by state law and school professionals are likely to be sensitive to the academic and social difficulties, which may be warning signs of hearing loss. The American Speech Language Hearing Association (ASHA) has established guidelines for audiologic screening of children (aged 5-18 years), which have largely been adopted by state agencies. ASHA recommends that children be screened upon entry into school, kindergarten, third grade, seventh grade and eleventh grades. The guidelines recommend pure tone audiometry screening at 1000, 2000, and 4000Hz at 20dB HL (ASHA, 1996). The child must respond reliably at 20 dB HL at all 3 frequencies in both ears to be considered a pass. Screening for middle ear function with tympanometry is recommended as part of a screening protocol with pure tone audiometry, but produces an unacceptably high false positive rate if conducted in isolation (ASHA, 1990). ASHA (1985) does not recommend screening at 6000Hz or higher due to the putative interactions between the transducer and the child's ear canals at that frequency. The decreasing wavelength with higher frequencies increases the probability that nulls will occur in the ear canal that significantly affect the sound pressure level at the tympanic membrane. The expected result would be an inflated failure and referral rate.

Key considerations for any diagnostic measure are its sensitivity and specificity. Sensitivity refers to the ability of a test to correctly identify a person with a particular disease. Specificity refers to the ability of a test to accurately identify people who do not have a particular

disease. Sensitivity is precisely defined as the probability that a person tests positive for the disease given that they in fact have the disease. If we denote the event T as “tests positive” and the event D as denoting “has the disease”, then the sensitivity is defined as $P(T|D)$ where the bar denotes that we are conditioning on the event “has the disease”. In other words, sensitivity is a *conditional probability*. Similarly, the specificity of a diagnostic measure is the probability that a person tests negative given that they do not have the disease. If we denote T^c as “tests negative” and D^c “does not have the disease”, then the specificity is given by $P(T^c | D^c)$. Knowing the specificity and sensitivity of a diagnostic measure and the *a priori* probability of the disease we can write the probability that a randomly selected person tests positive as

$$P(T) = P(T|D)P(D) + P(T | D^c)P(D^c)$$

Note that the complement probability of the specificity, $P(T | D^c)$, is the false positive rate, i.e. the probability that a person tests positive given that they do not have the disease. Since there is inevitable overlap between the distributions of persons with and without the disease on any diagnostic measure, there is a trade off between sensitivity and specificity. As the criterion level, or threshold for a “positive” test is made more stringent, specificity will increase and sensitivity will decrease. Conversely, as the criterion level is made less stringent, the sensitivity will increase as specificity decreases. Utilizing the screening protocol recommended by ASHA, Wallace and Laurenzo (2004) report that the sensitivity for pure tone screenings is 92%, while the specificity is 94%.

Using the above and the 0.003 as the *a priori* probability of hearing impairment, it is clear that the probability of a failed screening is $P(T) = (0.92)(0.003) + (0.06)(0.997) = 0.062$.

The probability of a failed screening can then be used to calculate the *positive predictive value*, which is the $P(D|T)$, the probability that a person has the disease given a positive test. By Bayes's theorem this is given by

$$P(D|T)=P(T|D)P(D)/P(T)=(0.92*0.003)/0.062=0.044$$

From the above we conclude that the *a posteriori* probability of hearing loss is 0.044 given a failed screening. While this is nearly an order of magnitude greater than the *a priori* probability, there is still a relatively small probability that a child has hearing loss in spite of a failed screening. For this reason, it is necessary to perform a 2nd screening before the child is referred. This will prevent an inflated referral rate and thereby reduce health-care costs. As the child is screened for a 2nd time, the new *a priori* probability of hearing loss is 0.044, in other words the *a posteriori* probability as a result of the 1st screening becomes the probability of disease in the 2nd screening reflecting our increasing certainty that the child has hearing impairment. Now the probability of a positive test is calculated to be $P(T)=(0.92*0.044)+(0.08*0.956)=0.11$ and by Bayes's theorem, the positive predictive value is $P(D|T)=P(T|D)P(D)/P(T)=(0.92*0.044)/0.11=0.37$

Through a two-step screening process with failures at both stages, our certainty of hearing loss has increased from 0.044 to 0.37 greatly reducing the number of over referrals.

1.2.1 Ohio Department of Health (ODH) Audiometric Screening Guidelines

The Ohio Department of Health (ODH) (1997) has established guidelines for audiometric screenings in the state of Ohio. The guidelines outline screening personnel qualifications, target population, screening procedures, and pass-fail and referral criteria. The guidelines were originally based on the guidelines set forth by ASHA in 1978, but are subject to an ongoing process of review and revision.

Personnel qualified to administer hearing screenings for school-aged children include school nurses, speech/language pathologists, and audiologists. Volunteers may also be used but may only be trained by school nurses, not audiologists. This training is allowed under the scope of practice in nursing in the state of Ohio. It is recommended that the volunteers have some background in health assessment. Instructions regarding hearing screenings and protocol are provided to screeners by ODH.

The target population for hearing screenings in the state of Ohio include children in kindergarten, first, third, fifth, and ninth grades. Preschoolers in public preschool programs should be screened upon admittance to the program and annually thereafter. Students in special classes such as resource rooms that correspond to the previously mentioned grades, and any student new to the school, regardless of grade should be screened. Children who have been previously identified as having a hearing loss and are currently utilizing amplification should be excused from the screening. Any child may be referred for a screening based on teacher concerns.

The screening procedure begins with a visual inspection of the ear. If discharge from the ear canal, malformation of the ear, or any soreness is noted, the child should be immediately referred and should not continue in the screening process. Pure tone air conduction screening is performed at 1000, 2000, and 4000Hz at 20dBHL. The inclusion of 500 Hz is optional. Tympanometry is optional, but is strongly recommended if 500Hz is not screened.

Children who fail the initial screening should receive a second screening no more than four to six weeks after the first screening. Children who do not pass both screenings should be referred for an audiological and medical evaluation. If a child passes pure tones, but refers on tympanometry, the child should be re-screened using both pure tones and tympanometry eight to

ten weeks later. A child who does not pass for the second time on tympanometry should be referred for an audiological and medical evaluation.

The Ohio Department of Health periodically compiles data collected from school hearing screenings. The most recent data available is from the 2001-2002 school year. The total number of students screened in elementary school was 790,248. An additional 11,000 students in preschool were screened. The referral rate in the 2001-2002 school year was 3%. Reportedly, nurses and speech language pathologists conducted 80% of the hearing screenings, and of the schools providing hearing screening, only 88% use the correct criteria of 20dBHL at 1000, 2000, 4000Hz.

1.2.2 The Need for Changes to the Screening Protocol

Many types of acquired and congenital hearing loss preferentially damage the base of the cochlea and progress apically. Examples of these types of hearing loss include ototoxic pharmacologic agents, noise exposure, and hearing loss associated with large vestibular aqueduct syndrome (LVAS). The current screening protocol limits screening to 4 kHz, which may not be high enough to identify children with these types of hearing loss in the early stages. Additionally, the frequency limitations inherent in ABR and OAE testing may fail to identify individuals with high frequency hearing loss, which a behavioral screening could identify if higher frequencies were included. On the other hand, the inclusion of 6 kHz could artificially inflate the probability of failing the 1st and 2nd screenings, which would lead to an unacceptably high referral rate. To date, the research on including higher frequencies in the screening protocol has been equivocal.

Several researchers have advocated for the inclusion of 6000Hz in the screening protocol (Axelsson et al, 1981; Holmes et al, 1997; Montgomery and Fugakawa, 1992; Niskar, 2001). They assert that many children are identified as at risk for hearing impairment through adding

higher frequencies to the screening protocol that would not be identified through the current 1-4 kHz protocol. Axelsson et al (1981) conducted a study involving 538 male teenagers (age 17-20) for hearing loss at 250, 500, 1000, 2000, 4000, 6000, and 8000Hz. They found hearing loss greater than 20dBHL in 15.5% of men tested. Hearing loss was most prevalent at 6000Hz, leading Axelsson and his colleagues to recommend that 6000 Hz be included in hearing screening protocols. A study by Montgomery and Fugakawa (1992) examined hearing thresholds of students in second, eighth, and twelfth grades. This study screened 1495 children- 598 2nd graders, 664 8th graders, and 233 12th graders. Screenings were performed at 2000, 4000, and 8000Hz at 25dBHL. The authors reported 5.9% of 2nd graders, 11.3% of 8th graders, and 12% of 12th graders were referred after failing a 2nd screening. This referral rate is much larger than the estimated prevalence of hearing loss in children, and may be attributed to the fact that 8000Hz was included in the screening protocol.

A study performed by Holmes et al (1997) included 6000Hz in the screening protocol. These researchers screened 342 students aged 10 to 20 years using 1000, 2000, 4000, and 6000Hz at 25dBHL. Additionally, tympanometry was performed on all students. Results were reported following an initial screening. Children who did not pass the initial screening were referred to the school nurse for a second screening. The failure rate of the initial screening was 17%. When data from 6000Hz was excluded from this study, the failure rate reduced to 7%. The authors attribute the high rate of failure to possible noise related hearing loss. These researchers concluded that 6000Hz should be included in the screening while cautioning that the high failure warranted further examination.

A recent focus on possible noise-induced hearing loss in the pediatric population has provided additional interest in including 6000Hz in hearing screenings. Once thought to be an

affliction of cumulative exposure appearing in middle age, media attention has now focuses on noise-induced cochlear loss in younger children. Perhaps the most often cited study of this phenomenon was done by Niskar and co-workers (Niskar et al., 2001). The authors attempted to estimate the prevalence of noise induced threshold shift (NITS) in children by screening children using tympanometry and air conduction thresholds at 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. NITS was defined by the following criteria:

1. Thresholds at 500 and 1000Hz had to be 15dB or better
2. The poorest threshold at 3000, 4000, or 6000Hz had to be 15dB poorer than the poorest threshold at 500 or 1000Hz
3. The threshold at 8000Hz had to be at least 10dB better than the poorest threshold at either 3000, 4000, or 6000Hz

The results of this study indicated that the overall prevalence of noise induced threshold shifts (NITS) in one or both ears was 12.5%. Boys had a significantly higher prevalence of NITS than girls. They also found that children 12-19 years had a significantly higher prevalence of NITS than children 6-11 years old. Niskar and colleagues (2001) noted that threshold shifts most commonly involve 3000, 4000, and 6000 Hz. Of the children who met the established criteria for NITS, not all three frequencies were affected equally. This study indicates that in NITS, 6000Hz is the most commonly affected frequency. Niskar et al (2001) concluded that because 6000Hz was involved 77.1% of the time that children experienced NITS, this frequency should be included in screening school-aged children. The prevalence data from this study suggests a very large number of children in the United States have noise induced threshold shifts, far more children than the reported prevalence data for hearing loss in children overall. However, there are several reasons for caution in interpreting the authors' conclusions. One major limitation of the study is that the NITS criteria do not preclude normal hearing. In fact, the authors admit that 18% of their NITS children had clinically normal hearing. An additional 57% of their NITS

children had audiometric findings that were within test-retest limits of normal hearing. Since the authors performed only an initial screening it is conceivable that 75% of their NITS children were in fact normal hearing individuals. Further, the authors fail to consider alternate explanations for reduced hearing at 6 kHz.

The assertion that noise-induced hearing loss is increasing in the pediatric population is not universally accepted. Rabinowitz and colleagues (2006) studied records of 2617 employees hired between 1985 and 2004 in an industrial plant. These employees were between the ages of 17 and 25 years with a mean age of 22.2 years. The employees were tested within 6 months of their start of employment with the company. They defined hearing loss as thresholds greater than 15dBHL at 500, 1000, 2000, 3000, 4000, and 6000Hz. By this definition, 16% of newly hired employees had high frequency hearing loss (3000, 4000, 6000Hz). The number of employees that had high frequency hearing loss did not change significantly over time. Rabinowitz and colleagues did not find an increase in hearing loss among their workers.

Mostafapour and colleagues (1998) conducted a study with 50 college students aged 18-30 years old. Each of these students listened to personal stereos at least one or more hours per day. No noise measurements were made, all data regarding noise exposure was collected via report of subjects involved in the study. An audiogram was completed on each student, and information was collected regarding amount of time spent listening to personal stereos. Thresholds were measured at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000Hz. No correlation was found between audiogram notching and amount of noise exposure. Researchers found more poor thresholds at 250Hz than any other frequency, and could not find a pattern correlating noise exposure and poorer thresholds at 3000-6000Hz.

Sadhra and colleagues (2002) completed audiograms in 21 individuals who worked in bars and dance clubs. Ages of the participants ranged from 20-25 years with the mean age as 22 years. Both pre and post shift audiograms were completed (500, 1000, 2000, 4000, 8000Hz), and the participants wore dosimeters throughout their shift to measure the level of noise they are exposed to while at work. Seven subjects were found to have hearing loss greater than 20dBHL for at least one frequency tested, and 4 had thresholds greater than 30dBHL before their shift at work. The average level of noise that any of the subjects were exposed to while at work was 89-98dB(A). The researchers found that thresholds at 4000Hz were more reliable predictors of threshold shifts related to noise levels in the bars and dance clubs that they worked in than lower or higher frequencies. Review of the literature suggests that more information is needed before adding 6000Hz to a screening protocol for children.

The aim of this study is to re-examine the inclusion of 6 kHz in the audiologic screening protocol. The standard screening protocol (1,2, and 4 kHz) will be compared against an experimental protocol including 6 kHz in a sample of 5th and 9th grade children. Failure rates will be examined on the basis of frequency, gender, and grade and compared against previous studies.

Methods and Results

2.1.1 Participants

Four hundred 5th and 9th grade students from the Columbus Catholic Diocese school district participated in this study. The 5th grade sample consisted of 148 children (70 Female; 78 Male). The 5th grade participants were between 10 and 11 years of age. Of the 252 9th grade participants, 131 were female and the remaining 121 were male. The following schools participated in the

study: St. Brigid of Kildare, St. Brendan, St. Pius X, St. Matthew, St. Francis DeSales, and Bishop Watterson. The study was conducted with the approval of the Ohio State University Institutional Review Board (IRB) and the permission of the Superintendent of the school system. No subjects were paid for their participation. Children who failed either the standard or experimental screening protocol were offered a free hearing evaluation at the Ohio State University Speech and Hearing Clinic.

2.1.2 Procedures

2.1.2.1 Data Collection

A letter and parental permission form was sent to the parents of the 5th and 9th grade students in the participating schools explaining the screening protocol (Appendix A). Additionally, information regarding privacy practices and sharing of health information (HIPAA compliance forms) were provided to the children's parents. Only children who returned both signed permission and HIPAA compliance forms were enrolled in the study. The children were screened in accordance with procedures outlined by the ODH. Prior to testing, verbal assent was obtained from each child screened. Each child was instructed with the same written script (Appendix B). The protocol for this study included visual inspection of the pinnae, otoscopy, 226-Hz tympanometry, and air conduction screening at 1000, 2000, 4000, and 6000Hz in both ears. The order that the tests were performed varied depending on the availability of equipment.

Audiometric screening was performed using 3 commercial audiometers with circumaural headphones: a Beltone model 110, a Beltone model 120, and a Maico MA39. All three audiometers are calibrated annually and were last calibrated on 9/22/06. Testing was performed from approximately January to April 2007. An EarScan screening tympanometer was used. No ambient noise measurements were made prior, during, or after testing. However, every attempt

was made to conduct the screenings in a quiet room. Prior to each screening session, a biologic calibration of the equipment revealed that all frequencies were audible under the test conditions.

Each child was screened at 1,2,4, and 6 kHz at a level of 20 dB HL in both ears. If the child initially failed the screening, the child was re-instructed, the headphones were repositioned and another test was administered. The test was considered a “fail” if any or all of the following occurred: a.) there was drainage from the ear, reported pain, cerumen impaction, or detected abnormality of the pinnae b.) a peak compensated static admittance of less than 0.3 mmhos was obtained in tympanometry, c.) the child failed to reliably detect any frequency in any ear at 20 dB HL. A decision was made to not exclude children who failed the otoscopic exam or tympanometry from the audiometric screening. The reasons for this were twofold. First, a child could fail the otoscopic examination for excessive cerumen and/or the presence of PE tubes. While these conditions may cause or be indicative of conductive hearing loss, it is possible to obtain thresholds within normal limits in these children. Further, the inclusion of otoscopy and tympanometry in this protocol is more stringent than what is likely encountered in a typical school screening program. Recall that ODH data indicate that 80% of school screenings are performed by non-audiologists, who may not be as proficient in performing and interpreting otoscopy and tympanometry.

2.1.2.2 Data Analysis

The data were analyzed for intergroup and intragroup differences based on gender, grade, frequency, and ear effects. Four subjects (3 5th graders and 1 9th grader) failed the otoscopy and/or tympanometry portion of the screening. Two of the 5th grade subjects had patent tubes bilaterally. These children also failed the audiometric screening at one or more frequencies. Data

analysis was conducted both with and without these subjects with no effect on the conclusions. Consequently, the audiometric data from these students is included in all subsequent analyses.

2.2 Results

A total of 40 subjects failed at least one frequency in one ear. In Figure 2.1 the total number of failures are presented by frequency. Note that the number of failures at each frequency in this Figure 2.1 may included individuals who also failed other frequencies.

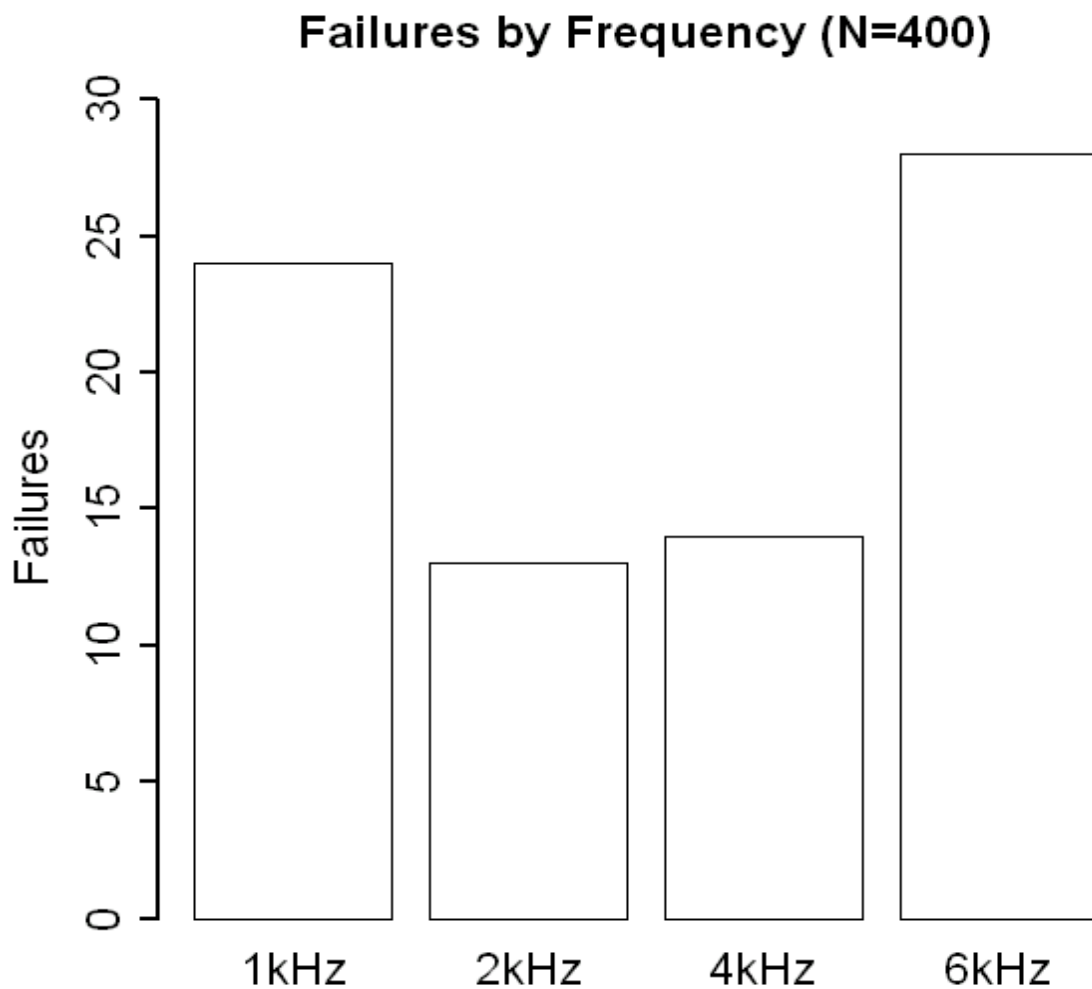


Figure 2.1: Failures by frequency for the entire sample of N=400 subjects. The number of failures at each frequency includes individuals who may have failed other frequencies as well.

The proportion of individuals who failed frequencies in one or both ears in isolation is shown in Figure 2.2. Note that no children failed 2 or 4 kHz in isolation. McNemar's test for dependent proportions revealed that a significantly larger proportion of children failed 1 kHz as compared to 2 and 4 kHz ($\chi^2=5.88$, $df=1$, $p=0.02$). Similarly, the proportion of subjects who failed 6 kHz in isolation was significantly larger than those failing 2 or 4 kHz ($\chi^2=10.31$, $df=1$, $p=0.001$). There was no significant difference between the number of subjects who failed 6 or 1 kHz in isolation ($\chi^2=0.32$, $df=1$, $p=0.57$).

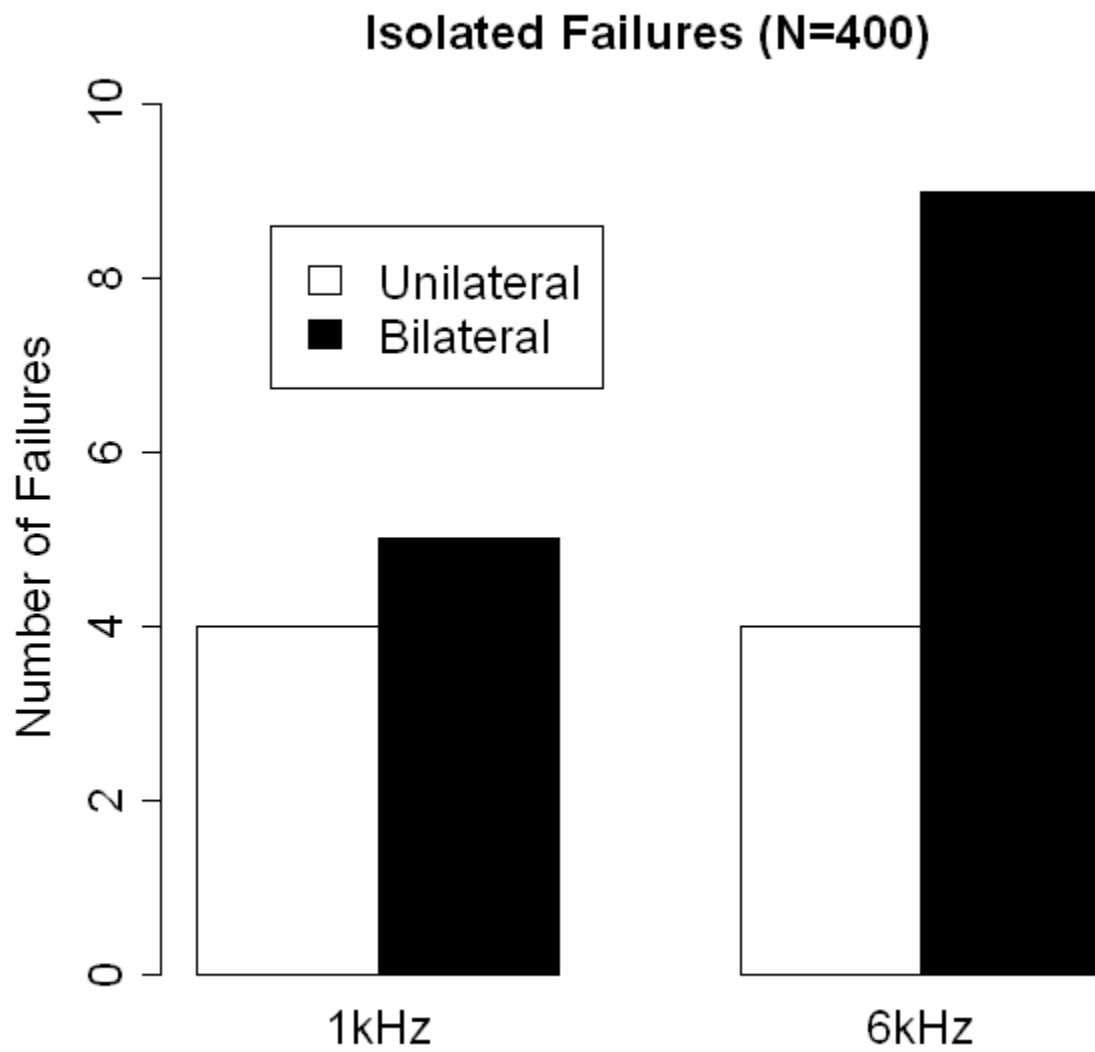


Figure 2.2: Unilateral and bilateral failures by frequency. The difference in proportion of children failing 1 and 6 kHz is not significantly different.

In Figure 2.3 the cumulative failures by frequency are shown

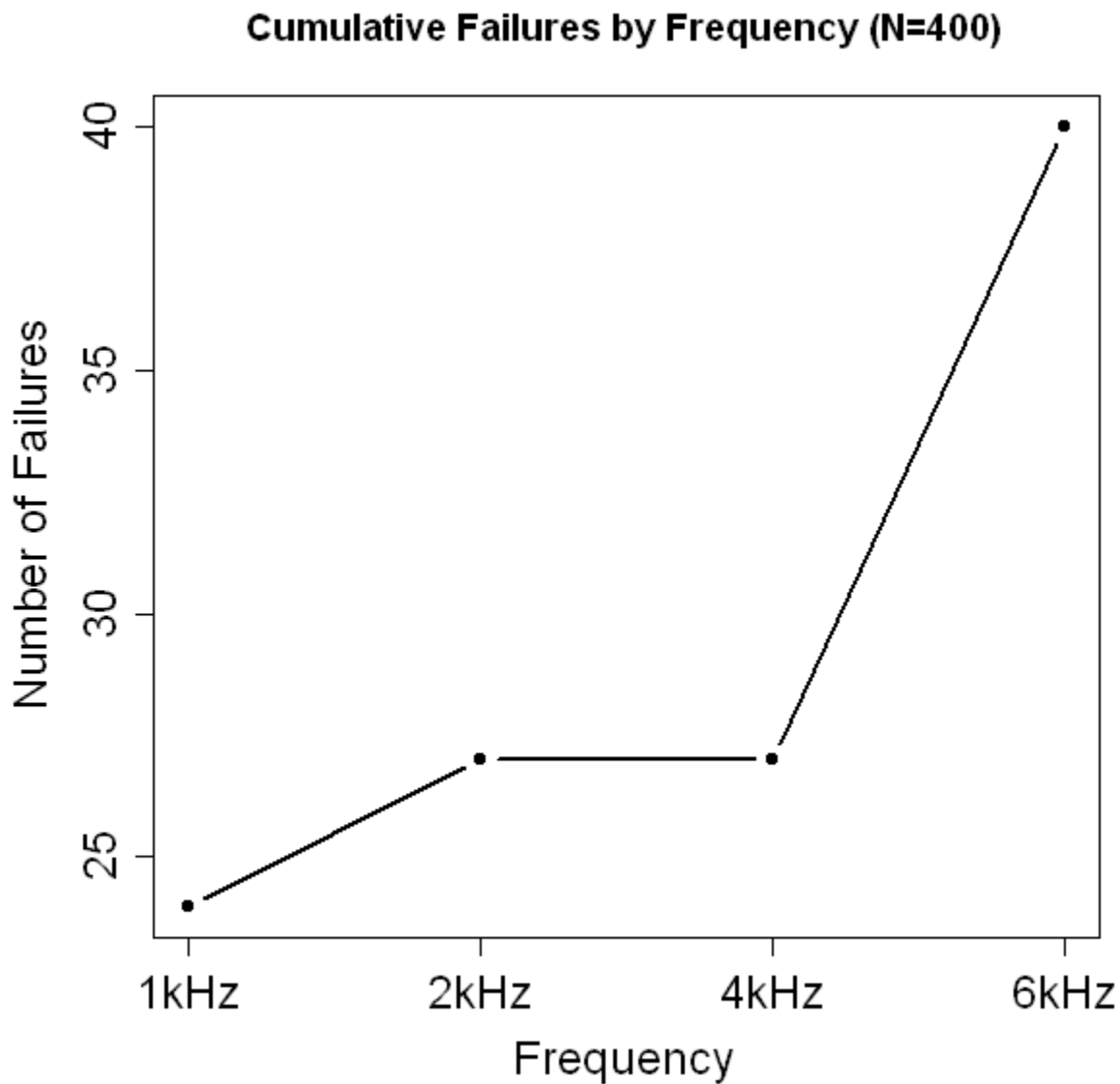


Figure 2.3: Cumulative failures by frequency for the entire sample (N=400). These cumulative totals include both unilateral and bilateral failures at each frequency.

McNemar's test for dependent proportions was used to analyze the increase in failures observed between the standard (1,2, and 4 kHz) and the experimental (1,2,4, and 6 kHz) protocols. The inclusion of 6 kHz significantly raised the failure rate from 6.75% to 10% ($\chi^2=11.02, df=1, p<0.001$).

In Figure 2.4, the cumulative failure proportions are presented by gender

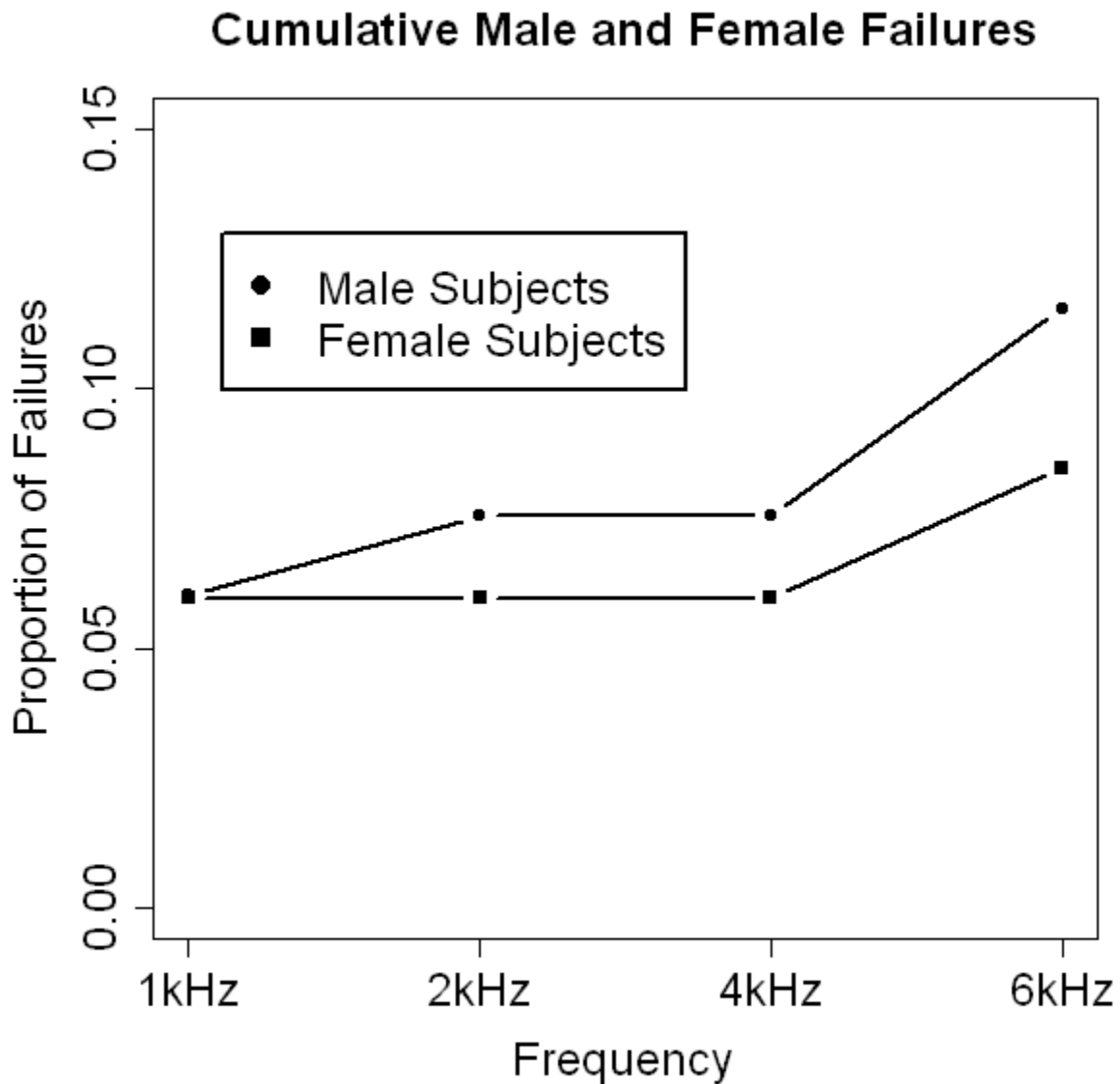


Figure 2.4: Cumulative failures by frequency and gender. The failure rates are displayed as proportions since the number of males and females are different.

When analyzed by gender, the significant difference between the standard and experimental protocol is dominated by the male contribution. The difference among the female subjects between the standard and experimental protocol fails to attain significance ($\chi^2=32.,df=1,p=0.07$) while the effect among males subjects is significant ($\chi^2=6.12,df=1,p=0.01$). In Figure 2.5, the failure proportions (expressed as percentages) are shown by gender and grade.

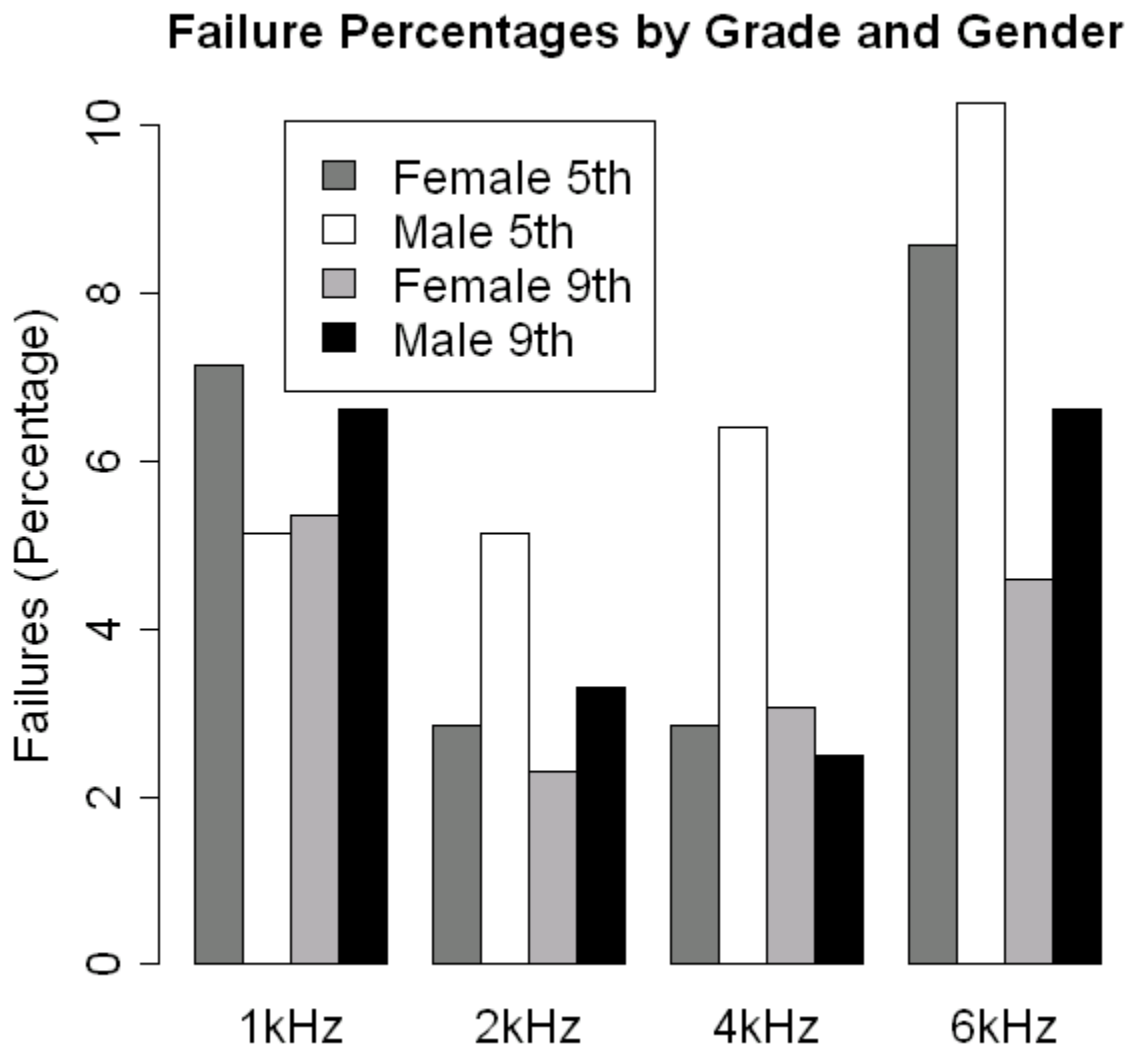


Figure 2.5: Percentages of failures by grade and gender. There were no significant findings by frequency between gender or grade.

Binomial tests of independent proportions showed that there was no significant effect for grade or gender at any of the frequencies. No significant difference was found between the proportion of females vs males on either the standard ($\chi^2=0.18, df=1, p=0.67$) or experimental protocols ($\chi^2=0.75, df=1, p=0.38$). Comparison by grade showed no significant difference between the 5th and 9th graders by frequency or protocol. Specifically, the apparent difference between the fifth and ninth graders shown in Figure 2.5 at 6 kHz failed to attain significance ($\chi^2=1.62, df=1, p=0.2$).

Discussion

In this study, the addition of 6 kHz in the school audiometric screening protocol was investigated. The inclusion of 6 kHz resulted in a significant increase of the failure rate from 6.75% to 10%. Among female subjects there was no significant difference in failure rate caused by the addition of 6 kHz, revealing that the overall significance was driven by an increase in failures among the male subjects. When direct comparisons were made on the basis of grade and gender, there were no significant differences in failure proportions by frequency or protocol. Among the previous studies conducted on the inclusion of 6 kHz in the screening protocol, the most comparable data was provided by Holmes et al. (1997). The failure rate in the previous study was significantly higher than found here ($\chi^2=7.19, df=1, p=0.007$). This may be attributable to the differences in age and other demographic differences between this study and the earlier investigation. Direct comparisons between this study and the Niskar et al. (2001) study are not supported due to the significant methodological differences. Comparison between the failure rate obtained in this study and the 2001-2002 referral rate reported by ODH (6.75% vs. 3%) revealed a significant difference. This is not unexpected given that the ODH data reports the percentage of children who failed two screenings.

There are several limitations in this study which caution against overinterpretation of the results. The first is lack of follow-up data for the children screened. A second screening would typically follow this screening before students were referred. Further, those students who fail a 2nd screening must administered an appropriate audiologic diagnostic battery before a determination of hearing impairment can be made. If the 2nd screening had been done on this sample, it would have allowed a direct comparison with the ODH referral rate from 2001-2002. It is certain that the proportion of failures on both the standard and experimental protocol contain

false positives, which would be uncovered on a 2nd screening and/or subsequent referral. The key question is what proportion of the failures with and without 6 kHz would ultimately be shown to be false positives. Accordingly, no sensitivity or specificity for these screening protocols can be determined.

Another limitation of this study is that noise measurements were not taken in the rooms in which screenings were performed. Although a biologic calibration of the equipment revealed that all frequencies screened were audible, a 1/3 octave band analysis of the ambient noise might offer some explanation for the significant differences in fail rates observed as a function of frequency.

In spite of its limitations, this study provides some intriguing preliminary findings. In support of previous studies, a significant increase in fail rates was observed with the addition of 6 kHz. Further, an analysis by gender showed that male children were the largest contributor to that increase. However, no gender differences or grade differences were found when direct comparisons were made by frequency or protocol. If the increased fail rate at 6 kHz is attributable to noise exposure as previous studies have suggested, it would be expected that older children would show more evidence than younger ones. This was not found to be the case in this study. The critical component which must be included in future studies to determine the appropriateness of 6 kHz in the screening protocol the identification and tracking of a cohort of failures through the 2nd screening and referral process.

References

- American National Standards Institute. (2002). ANSI S1260-2002. Acoustical performance criteria, design requirements, and guidelines for schools. Melville, NY:Author.
- American Speech-Language-Hearing Association (1990). Guidelines for Screening Hearing Impairments and Middle Ear Disorders. *ASHA*, 32 (Suppl. 2), 17-24.
- ASHA. (2000). JCIH Year 2000 Position Statement: Principles and Guidelines for Early Hearing Detection and Intervention Programs. Available from www.asha.org/policy
- Audiologic Screening Panel. (1996). *Guidelines for Screening for Hearing Impairment- School-Age Children, 5 Through 18 Years*. Rockville, MD.
- ASHA. (1985). *Guidelines for Identification Audiometry*. Rockville, MD.
- Axelsson, A., Jerson, T., Lindberg, U., Lindgren, F. (1981). Early noise induced hearing loss in teenaged boys. *Scandinavian Audiology*, 10(2), 91-96.
- Blanchfield, B., Feldman, J., Dunbar, J. (2001). The severely to profoundly hearing impaired population in the United States: Prevalence estimates and demographics. *Journal of the American Academy of Audiology*, 12(4), 183-189.
- Centers for Disease Control and Prevention. (2006). Frequently asked questions on general information on hearing loss. Retrieved May 4, 2007 from www.cdc.gov/ncbddd/ehdi/FAQ/questionsgeneralHL.htm
- Cunningham, M., & Cox., E.O. (2003). Hearing assessment in infants and children: Recommendations beyond neonatal screening. *Pediatrics*, 111, 436-440.
- Erenberg, A., Lemons, J., Sia, C., Trunkel, D., and Zirng, P. (1999). Newborn and infant hearing loss: Detection and intervention. *Pediatrics*, 103(2), 527-530.
- Gorga, M., Norton, S., Sininger, Y., cone-Wesson, B., Folsom, R., Vohr, B., Widen, J., and Neeley, S. (2000). Identification of neonatal hearing impairment: Distortion product otoacoustic emissions during the perinatal period. *Ear and Hearing*, 21(5), 400-424.
- Govaerts, P., Casselman, J., Daemers, K., DeCeleulaer, G., Somers, T., Offeciers, F. (1999). Audiologic findings in large vestibular aqueduct syndrome. *International Journal of Pediatric Otorhinolaryngology*, 51(3), 157-164.
- Holmes, A., Kaplan, H., Phillips, R., Kemker, F., Weber, F., Isart, F. (1997). Screening for Hearing Loss in Adolescents. *Language, Speech, and Hearing Services in Schools*, 28, 70-74.

- Johnson, C., Stein, R., Broadway, A., Markwalter, T. (1997). "Minimal" High Frequency Hearing Loss and School-Age Children: Speech Recognition in a Classroom. *Language, Speech, and Hearing Services in Schools*, 28, 77-84.
- Joint Committee on Infant Hearing. (2000). Year 2000 position statement: Principles and guidelines for early hearing detection and intervention program. *Audiology Today*, 12, Special Issue, August, 7-27.
- Kemper, A.R., & Downs, S.M. (2000). A cost-effectiveness analysis of newborn hearing screening strategies. *Archives of Pediatric and Adolescent Medicine*, 154, 484-488.
- Logemann, J. and Baum, H. (1998). Speech-Language-Hearing Interventions in the Schools: A Public Health Perspective on Measuring their Short and Long Term Impact. *Language, Speech, and Hearing Services in Schools*, 29, 270-273.
- Mostafapour, S., Lahargoue, K., and Gates, G. (1998). Noise induced hearing loss in young adults: The role of personal listening devices and other sources of leisure noise. *Laryngoscope*, 108(12), 1832-1839.
- Montgomery, J. and Fujakawa, S. (1992). Hearing Thresholds of Students in the Second, Eighth, and Twelfth Grades. *Language, Speech, and Hearing Services in Schools*, 23, 61-63.
- Milunsky, J.M., Maher, T.A, Yosunkaya, E., & Vohr, B.R. (200). Connexin-26 gene analysis in hearing-impaired newborns. *Genetic Testing*, 4,345-349.
- Niskar, A., Kieszak, S., Holmes, A., Esteban, E., Rubin, C., Brody, D. (2001). Estimated Prevalence of Noise-Induced Hearing Threshold Shifts Among Children 6 to 19 Years of Age: The Third National Health and Nutrition Examination Survey, 1988-1994, United States. *Pediatrics*, 108, 40-43.
- Ohio Department of Health (1997). Policies for Hearing Conservation Programs for Children.
- Rabinowitz, P., Slade, M., Galusha, D., Dixon-Ernst, C., and Cullen, M. (2006). Trends in the prevalence of hearing loss among young adults entering an industrial workforce 1985-2004. *Ear and Hearing*, 27(4), 369-375.
- Sahra, S., Jackson, C., Ryder, T., and Brown, MJ. (2002). Noise exposure and hearing loss among student employees working in university entertainment venues. *Annals of Occupational Hygiene*, 46(5), 455-463.
- Sininger, Y., Cone-Wesson, B., Folsom, R., Gorga, M., Vohr, B., Widen, J., Ekelid, M., and Norton, S. (2000) Identification of neonatal hearing impairment: Auditory brainstem response testing during the perinatal period. *Ear and Hearing*, 21(5), 383-399.
- Smith, R., Bale, J., and White, K. (2005). Sensorineural hearing loss in children. *Lancet*, 365, 891-902.

- Thompson, D., McPhillips, H., Davis, R., Lieu, T., Homer, C., and Helfand, M. (2001). Universal newborn hearing screening: A summary of the evidence. *Journal of the American Medical Association*, 286(16), 2000-2010.
- Wallace, R. and Laurenzo, J. (2004). Screening for Hearing Impairment: Guide to Clinical Preventative Services. Retrieved 28 April 2007 from www.ahrq.org/clinic/2ndcps/hearing.pdf
- Yoshinaga-Itano, C., Sedey, A., Coulter, D., and Mehl, A. (1998). Language of early- and later-identified children with hearing loss. *Pediatrics*, 102(5), 1161-1171.

APPENDIX A

Parent permission

CONSENT FOR PARTICIPATION IN SOCIAL AND BEHAVIORAL RESEARCH CONSENT TO INVESTIGATIONAL TREATMENT OR PROCEDURE

Title of the Study: Revisiting Hearing Screening Protocol for Fifth and Ninth Grades to include 6000Hz.

Principal Investigator: Gail M. Whitelaw, Ph.D.

Location: These screenings will take place at your child's school. If your child does not pass the screening, a diagnostic evaluation will be offered at the Speech-Language-Hearing Clinic, The Ohio State University, West Campus, Pressey Hall, 1070 Carmack Road.

Description of the Study: The purpose of this study is to determine whether or not the Ohio Department of Health should expand the protocol for hearing screenings to include 6000Hz. The results may help us to identify children at risk for high frequency hearing loss who are not currently identified through the screening process.

Procedures: Your child's hearing will be screened using the Ohio Department of Health's screening guidelines. He/she will be asked to listen to a series of tones and indicate when he hears the tones. A test of middle ear function will be completed as well, in which your child does not need to respond. Your child will not be pressured in any way. If your child does not pass the screening, a diagnostic evaluation will be offered free of charge at The Ohio State University Speech-Language-Hearing Clinic.

Risks and Benefits: There appear to be no risks involved in your child's participation in the study outside of the inconvenience of the time taken from his or her usual routines. The major benefits of this study will be in the future and will relate to the possible changes in the screening protocol of children in the state of Ohio.

Estimated Amount of Time: The screening will require one visit of approximately five minutes in duration. If your child does not pass the screening, and you wish to have a full diagnostic evaluation free of charge, that evaluation would last no longer than one hour.

Confidentiality: Each child in the study will be assigned a participant ID. All the information will be analyzed and reported by the number. Only the researchers will have access to the names associated with the ID. Thus, anonymity of the children will be preserved. No information about your child will be made available to others unless you so request.

Rights: You have the right to have any questions regarding the research or your child's participation in the study answered now or in the future. You have the right to receive the results of the hearing screening. The principal investigator, Dr. Gail Whitelaw, is the Director of Clinical Instruction and Research at the Ohio State University and can be reached at 614-292-

6251. You may withdraw your child from this study at any time. You will receive a copy of this form.

Consent:

I consent to my child's participation in research being conducted by Gail M. Whitelaw of The Ohio State University and her assistants and associates.

The investigator has explained the purpose of this study, the procedures that will be followed, and the amount of time it will take. I understand the possible benefits, if any, of my child's participation.

The investigator has explained the risks, if any, and I understand what they are. No guarantees have been made regarding the effectiveness of this procedure.

I know that my child can choose not to participate without penalty to him or her. If I give my consent to participate, my child can withdraw from the study at any time, and there will be no penalty.

I consent to the use of the self-reported personal and academic information concerning my child.

I have had a chance to ask questions and obtain answers to my questions. I can contact the investigators at 614-292-6251. If I have questions about my rights as a research participant I can also contact the Office of Research Risks Protection at 614-688-4792.

I understand in signing this form that, beyond giving consent, I am not waiving any legal rights I might otherwise have. My signature on this form does not release the investigator, the sponsor, the institution, or its agents from any legal liability for damages that they might otherwise have.

I have read this form or have had it read to me. I sign it freely and voluntarily. A copy has been given to me.

Participant's name:

Participant's date of birth:

Age:

Signature of parent or guardian:

Date:

Principal investigator or his/her authorized representative:

Please circle if you would like to be informed of the results of this study yes no

Thank you for allowing your child to participate in the study!

APPENDIX B

Verbal Script: Hearing Screening Protocol for 5th and 9th graders

You are going to have a hearing screening today.

I am going to take a look in your ear with this ear light. All you need to do is sit quietly. Do you have any questions?

I am now going to place this small rubber button next to your ear and you will feel a puff of air. This shows me how well your eardrum is working. Let me know if you have any questions.

I am going to place the headphones over your ears. When you hear a tone or ‘beep’, please raise your hand. When the tone disappears, put your hand down. These tones will be very soft or faint, just do your best to raise your hand when you hear the tone. We will start with your _____ ear.

Good job, now we are going to switch to your _____ ear.

Thanks for being so cooperative with the hearing screening. We’ve completed the screening, do you have any questions?